DAHLGREN DIVISION
NAVAL SURFACE WARFARE CENTER
Dahlgren, Virginia 22448-5100

NSWCDD/MP-94/363

DETECTION RANGE PERFORMANCE–HORIZON INFRARED SURVEILLANCE SENSOR (HISS)

BY PATRICK A. DEZEEUW
SHIP DEFENSE SYSTEMS DEPARTMENT

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FOREWORD

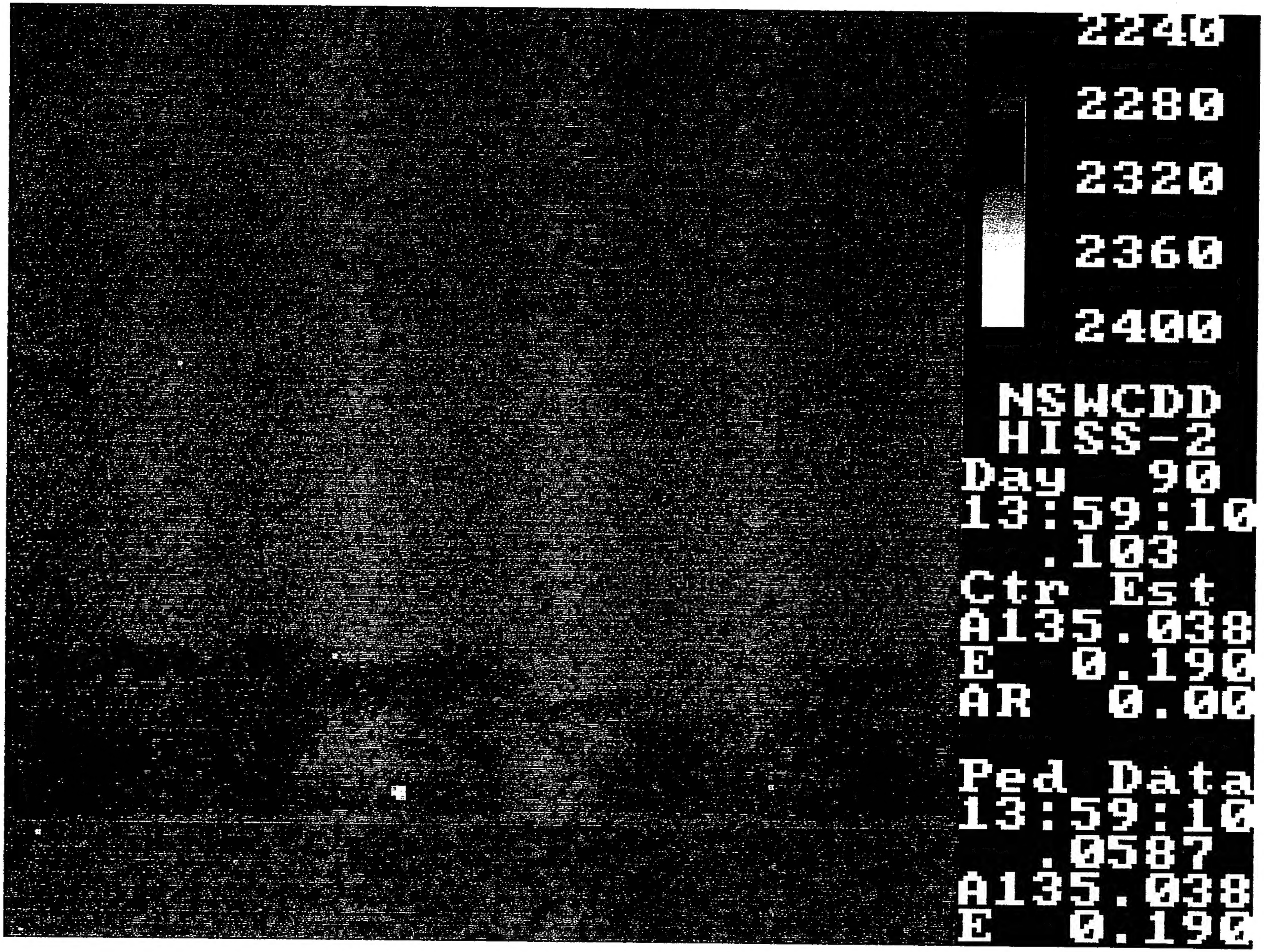
The Horizon Infrared Surveillance Sensor (HISS) Phase 2 system was involved in field testing at Wallops Island, Virginia from November 1993 through April 1994. This report discusses the HISS project and presents results from the analysis of system detection range performance. The HISS Phase 2 detection range performance has been used to demonstrate IR contributions to an integrated sensor system and to verify detection range predictions and improve the fidelity of current detection range performance models.

I wish to acknowledge the following members of the HISS test team for the operation of the HISS system during the data collection period: Everett Bryant, Connie Huffman, Keith Merranko, Sheldon Zimmerman, Ken Hepfer and Robert Headley.

This report has been reviewed by Roger Carr, Head, Photonic Systems Branch and Stuart Koch, Head, Search and Track Division.

Approved by:

T. C. PENDERGRAFT, Head
Ship Defense Systems Department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NSWCDD
HISS-2
Day 90
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This report presents preliminary results from our recent field tests of the Horizon Infrared Surveillance Sensor (HISS) Phase 2 system performed by the Photonic Systems Branch at the Naval Surface Warfare Center, Dahlgren Division (NSWCDD).

Detection Range Performance
Horizon Infrared Surveillance Sensor

Analysis of Test Data Collected at NSWCDD / Wallops Island Detachment, November 1993 through April 1994

Patrick A. Dezeeuw
Photonic Systems Branch, Code F44
Naval Surface Warfare Center, Dahlgren Division

A background of the HISS system and a description of the Wallops Island test setup are provided. The variation in the intensity of a towed, height-keeping target known as the TLX-1 and an explanation of this variation are also provided.

The detection range performance data for 25 TLX target runs is presented, and an analysis of this data in a number of different formats is provided. The performance prediction analysis that was done is described and compared with the Wallops Island test results.

Finally, data results are summarized and conclusions provided.

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Outline

- HISS Introduction / System Description
- Wallops Island Test Description
- Description of TLX Target
- Detection Range Performance Data
- Comparison with Predicted Performance
- Summary

The primary goal of the HISS project is to provide risk reduction to the surface Navy's IRST engineering and manufacturing development by demonstrating basic horizon IRST hardware.

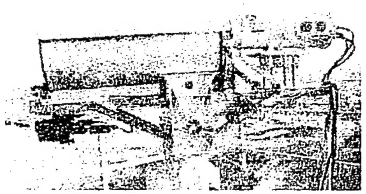
This includes the development at NSWCDD of special target detection-discrimination algorithms which were implemented in real-time hardware.

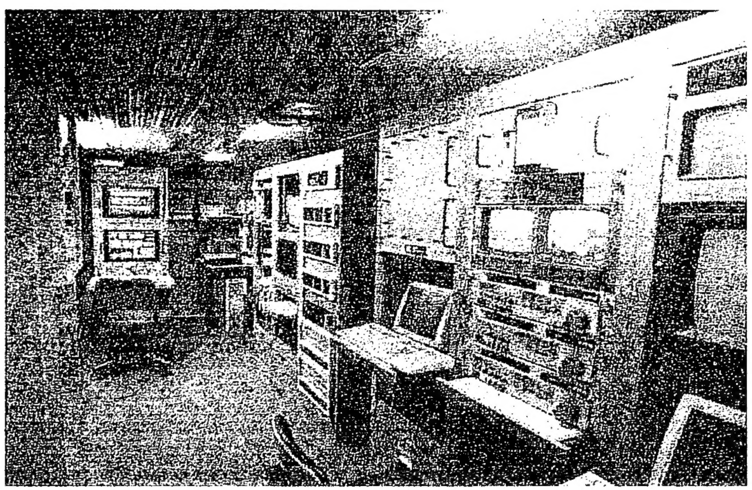
The HISS project was developed to support on-going experiments in the area of multi-sensor integration (MSI).

Another important goal is to use the data gathered to compare predicted detection range performance against achieved performance to validate current IRST performance models.

Also from these tests, we have collected a large database of high resolution, high sensitivity digital video imagery which includes target, background and clutter data. The data gathered and lessons learned will be passed to follow-on efforts.

Goals of the HISS Project





- Demonstrate basic horizon IRST hardware
- Develop / Implement real-time target detection processing
- Demonstrate IR contributions to an integrated sensor system
- Verify detection range predictions
- Provide data and experience for follow-on efforts
  - high resolution / high sensitivity images
  - land background data
  - solar clutter data
  - etc.

The HISS project follows a phased approach to reduce risk and provide interim capability. Each phase focuses on a certain part of the Infrared Search and Track (IRST) detection problem. Lessons learned from each phase are applied to the next phase.

• In Phase 1, data was recorded using a high resolution, high sensitivity, 3-to 5-μm staring sensor at the Wallops Island facility. In the follow-on data analysis effort, target detection algorithms were developed which provided suitable target detection performance in terms of detection range in non-real time.

• In Phase 2, previously developed signal processing algorithms in a real time signal processor were implemented. The team also participated in real-time multisensor integration (MSI) testing.

• In Phase 3, both sensor and processing aspects of the system are upgraded to demonstrate a full performance horizon IRST. The Phase 3 system is also designed to gather data to evaluate the merit of dual subband operation as an additional discrimination tool.

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Three Phase Approach

- Phase 1
  - prototype a sensor of requisite sensitivity and resolution
  - develop target detection algorithms (non-real time)
- **Phase 2**
  - **prototype real time signal processor which implements the algorithms developed under phase 1**
  - **develop interface to MSI processor**
- Phase 3
  - prototype mirror stabilized scanner configuration
  - upgrade signal processor capacity

The HISS system is designed to address the most stressing threat to the ship's combat system under a wide variety of weather conditions.

The system must have the resolution to discriminate targets from clutter near the horizon. This equipment is designed to be a component of multi-sensor integration system and must have a false alarm rate (FAR) consistent with MSI operation.

The system is designed for land-based and shipboard field testing.

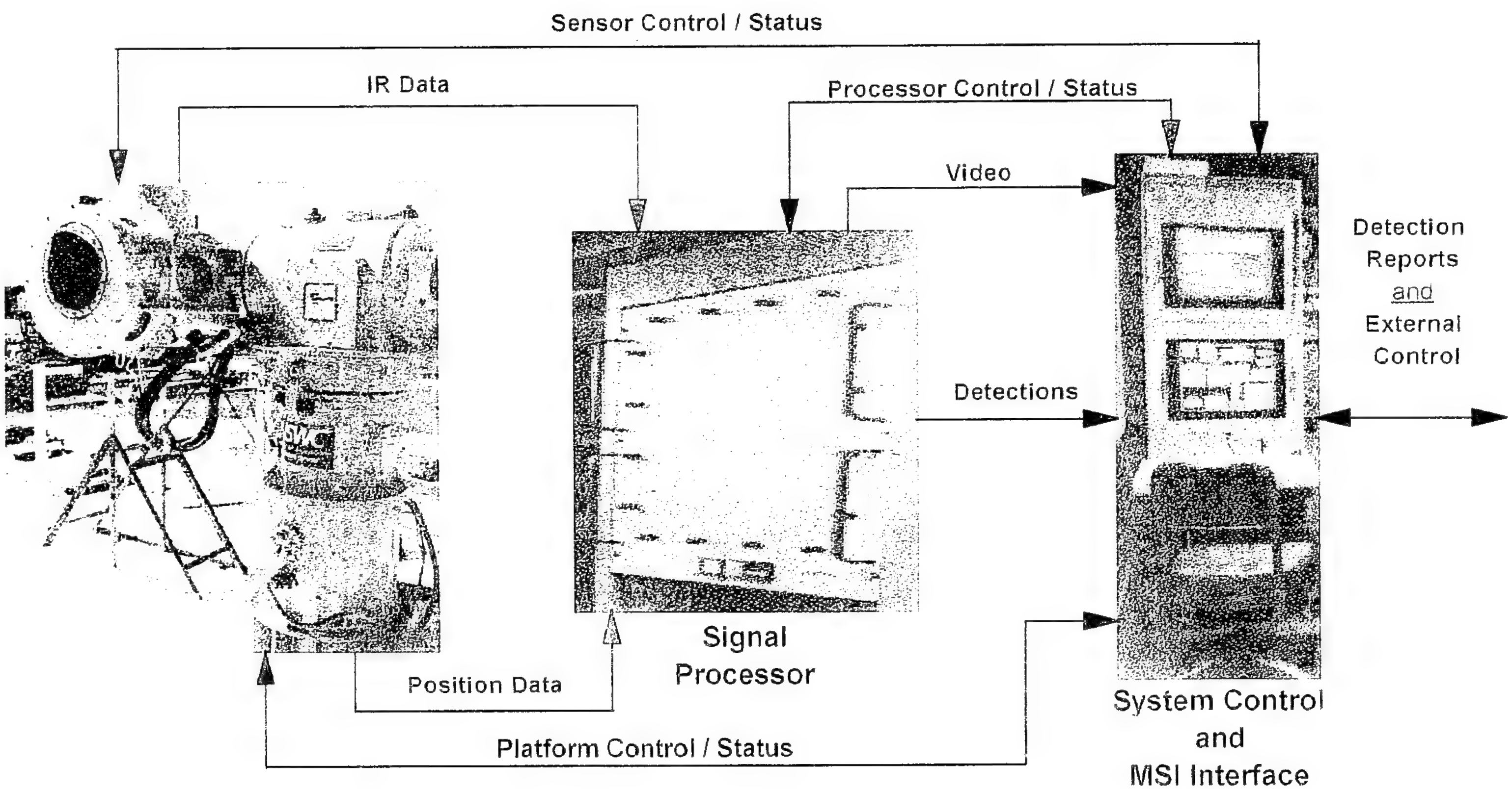
The system must process infrared (IR) imagery, develop detections and provide those detections to an MSI processor with minimal latency. (Typically, the detection report will leave the system less that 100 msec after the IR radiation first impinges on the sensor.)

Level of Performance Required

- Detect supersonic (M2+), low flying targets at the horizon limit under most weather conditions
- Discriminate targets from near horizon clutter with a FAR consistent with MSI operation
- Operate in both land-based and shipboard test environments
- Provide target information in real-time to an external interface

This figure shows how the sensor and pedestal data are processed into detection reports that are sent to the system control center for transmittal to the MSI interface.

HISS Phase 2
System Block Diagram

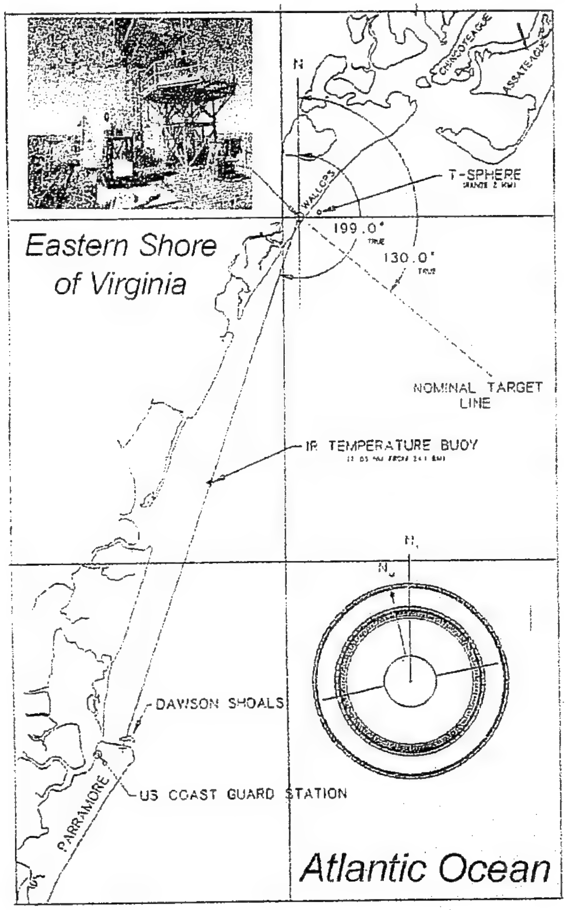


Field testing of the HISS Phase 2 system took place at Wallops Island Detachment, NSWCDD from November 1993 through April 1994.

This test location is a fully instrumented test range on the eastern shore of Virginia that allows for presentation of targets in a littoral environment.

This map shows the location of the test site with respect to the line-of-site of the targets.

Map of the Wallops Island Test Area



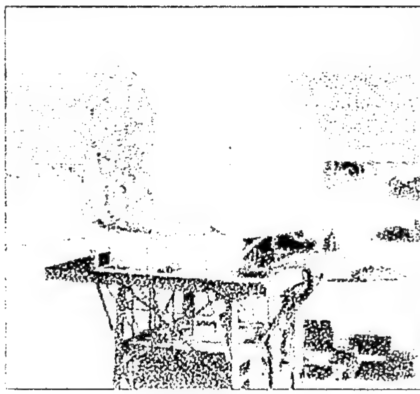
- Tests were performed at the Wallops Island Detachment of the Naval Surface Warfare Center / Dahlgren Division
- This is an instrumented test range on the Atlantic Ocean
- The nominal target line for aircraft, towed targets, and boat targets was 130 to 140° True.
- Variable height targets were also located at Parramore Island on 199° True.

This is the suite of equipment that participated in MSI testing at Wallops Island. The sensor and scanner for the HISS Phase 2 system is shown in the upper right.

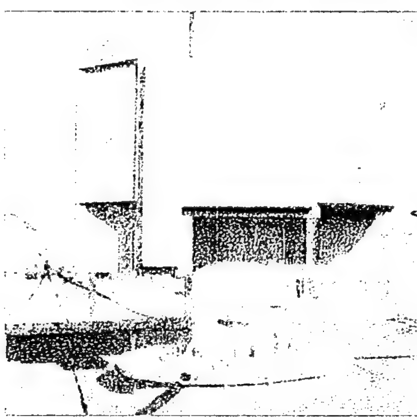
The equipment used in this test operated in real time to provide information to an MSI processor, which could then selectively cue the sensors. For instance, the HISS search zone could be cued based upon a radar contact.

The experiment also included a suite of IR and radio frequency (RF) propagation measurement equipment and meteorological data collection equipment.

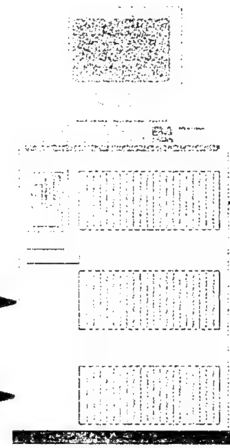
Wallops Island Experiment Equipment



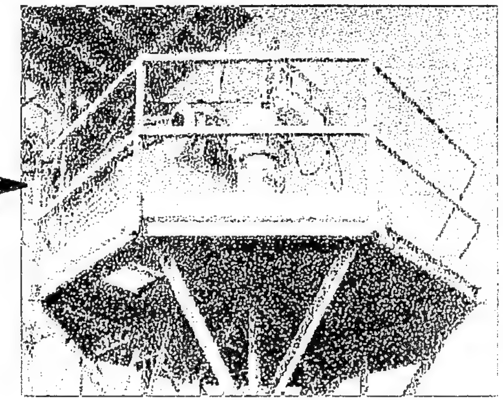
Radar

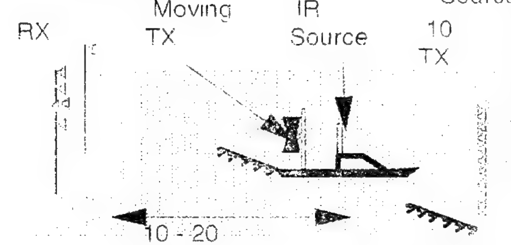


Electronic Support Measures



MSI Processing





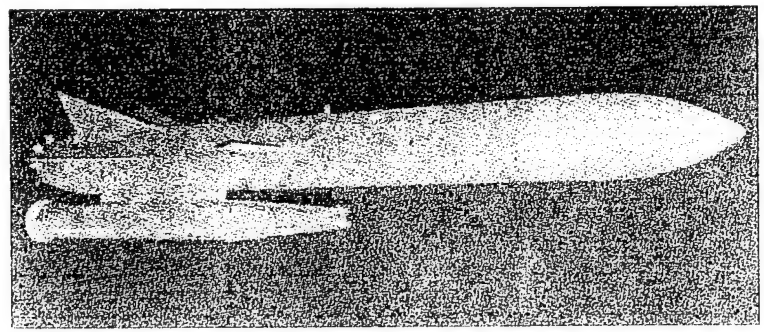
PROPAGATION MEASUREMENT

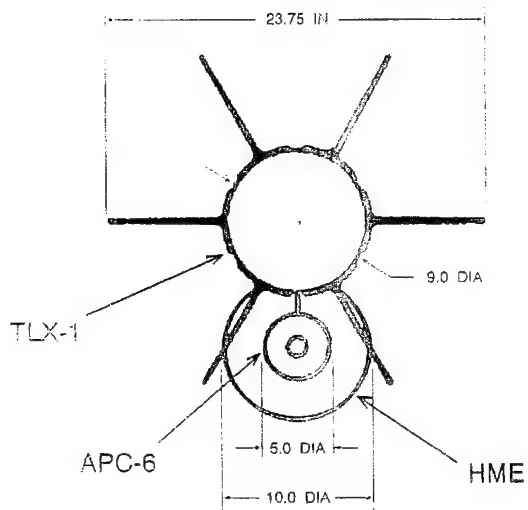
The subject of this report is the detection range performance of the HISS Phase 2 system against the TLX-1 towed, height-keeping target configured with an APC-6 plumer and hot metal emitter (HME). The APC-6 has an HME to produce IR radiation with spectral content more characteristic of the body radiation from a supersonic (Mach 2+) cruise missile.

Originally the HME had a diameter of 6.54 in. and a measured IR signature of 6 W/sr in-band. For the purpose of this test, it was replaced with a new configuration that has a 10-in. HME. The IR signature for the 10-in. HME was calculated to be about 20 to 40 W/sr. Unfortunately, the 10-in. HME had an unforeseen consequence on the drag of the TLX target that will be discussed latter.

This figure shows a side-aspect picture of the TLX with the 6.5-in. HME and a front-aspect diagram of the TLX with the 10-in. HME. It also shows some sample imagery of the TLX at a range of 15.7 nmi and an altitude of 30 ft.

TLX - Towed, Height-Keeping Target with Plumer and Hot Metal Emitter





HISS Phase 2 Recorded Image
TLX, altitude: 30 feet, Range: 15.7 Nmiles

Adding the 10-in. HME resulted in increased drag on the lower rear of the TLX, which caused it to fly with the nose tilted down. Review of video taken with a Wallops Island surveillance video camera shows the TLX tilt-down angle to be approximately 5 deg.

As shown in this illustration, it is clear that when the line-of-sight to the target is exactly nose-on, there will be major obstruction of the HME. The HME is visible only when looking at the target from a side-aspect angle.

Further confirmation of this effect is shown next.

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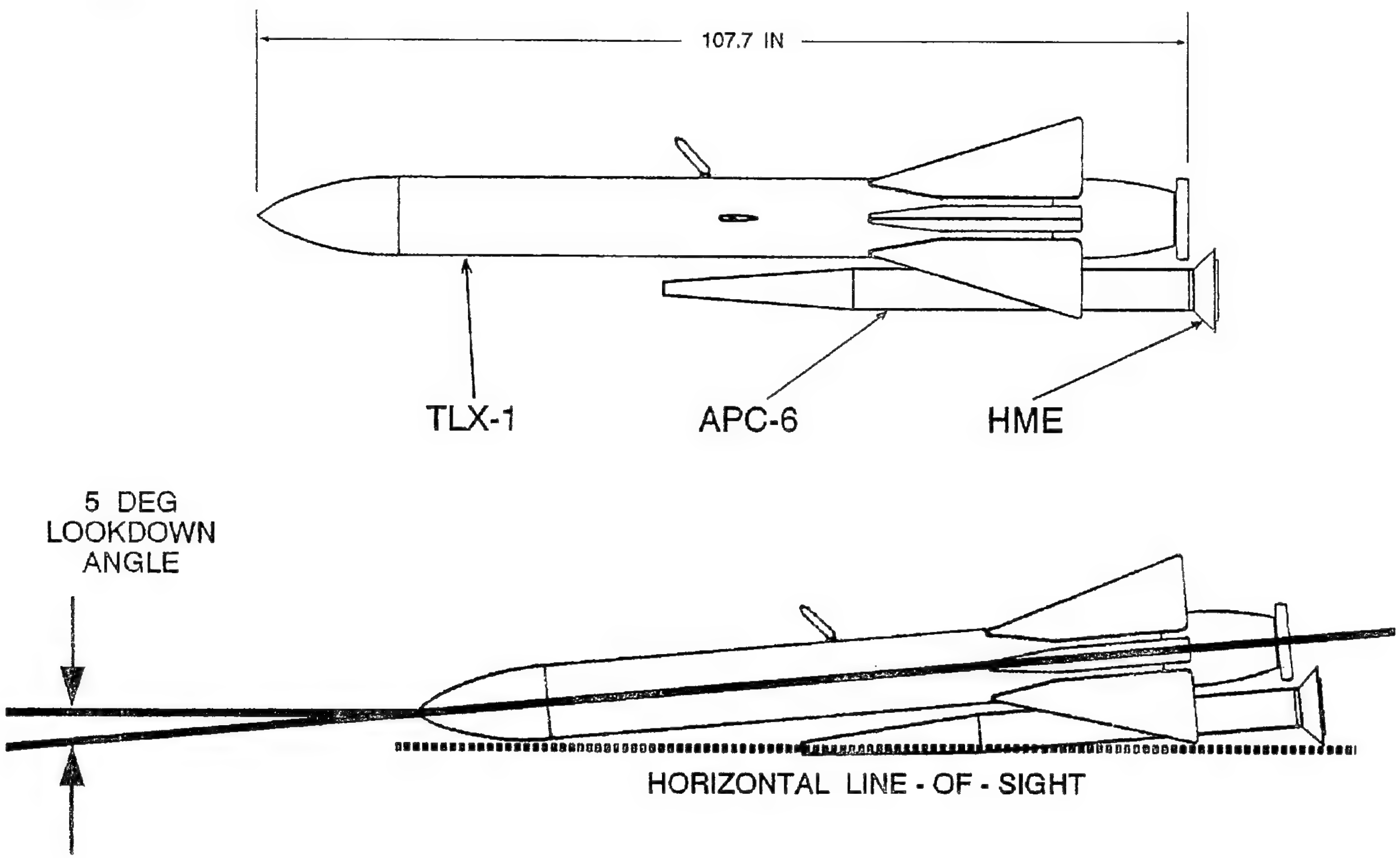
Effect of Drag on TLX
Obscuration of HME



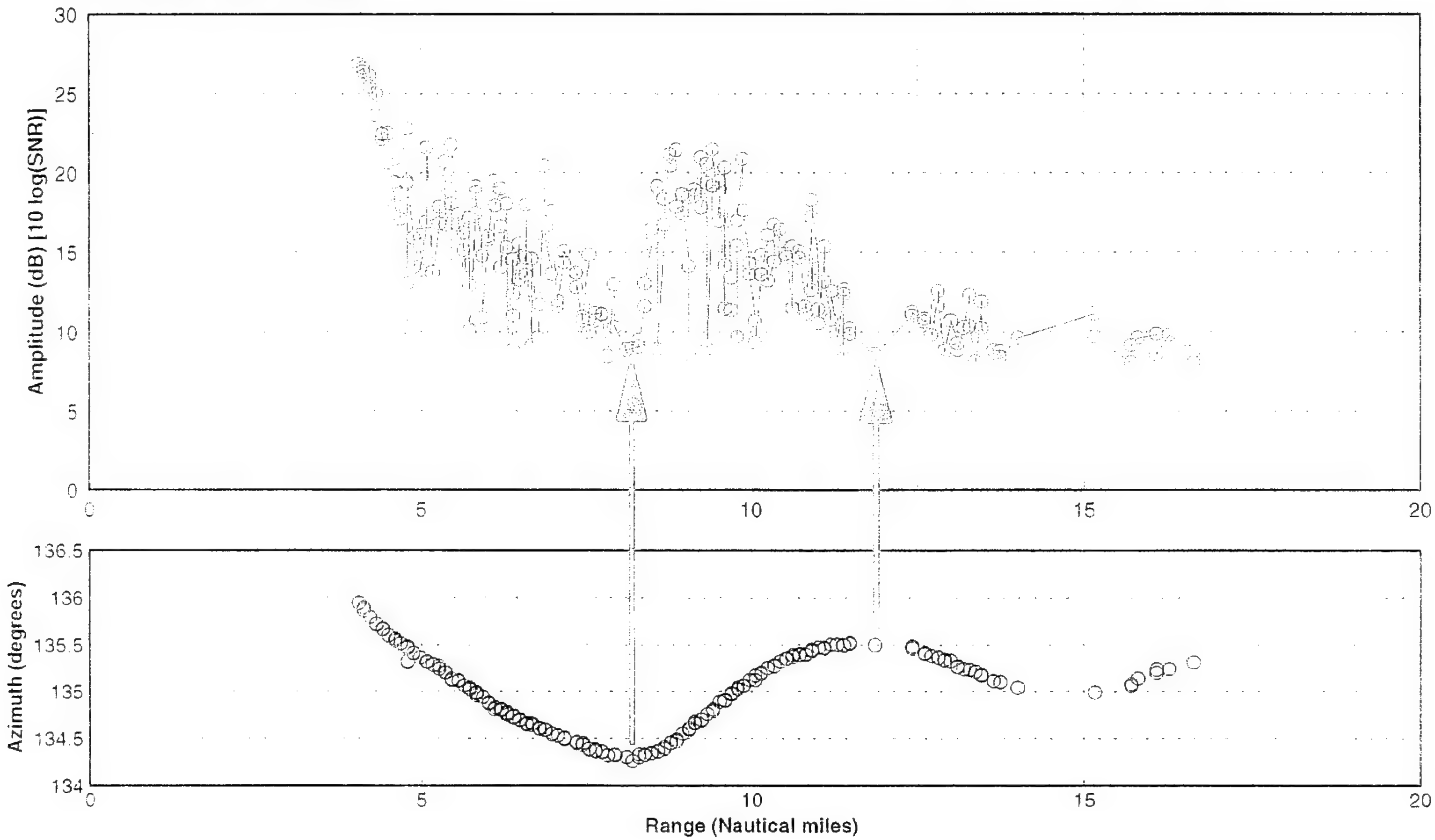
This is a sample of HISS detection data for event MSI-1, run 6, on March 22, 1994, which shows the target amplitude versus range compared with the target azimuth versus range.

From this comparison, it is clear that the maximum amplitude occurs when the target is at a side-aspect angle and that the minimum amplitude occurs when the target is at a front-aspect angle. This data sample is representative of all the TLX runs.

This data sample is further confirmation that the TLX was flying nose down and obscuring the HME when at a front-aspect angle.

Although this obstruction resulted in large variations in the apparent intensity of the TLX, the HISS performed extremely well at detecting the target.

Amplitude Variation
Amplitude Nulls and Target Motion



Before presenting the detection range results, some of the signal processor functions need to be described. The major steps in the signal processor are: the spacial filter to suppress extended objects the adaptive threshold to achieve an approximate constant FAR over the field of view and the single-scan discrimination function to rate each detection as to how *target like* it is. Comprehensive target metric (CTM) is the numerical value used to rate detections.

Although the signal processor is capable of producing up to 1000 detection reports per second, the threshold multiplier within the signal processor was usually set to produce something on the order of 100 reports per second or less.

Within the system control center (SCC), there is a CTM threshold function to further limit the detection reports sent out of the system to the multisensor integration program (MSIP). During MSI testing, the CTM threshold was typically set at 0.15 but was often raised to as much as 0.25 in cases of extreme clutter. The FAR out of the system to the MSIP was typically less then 0.01/sec.

Note that within the SCC, the data extraction function records all of the detection reports and this is the source for the detection range analysis.

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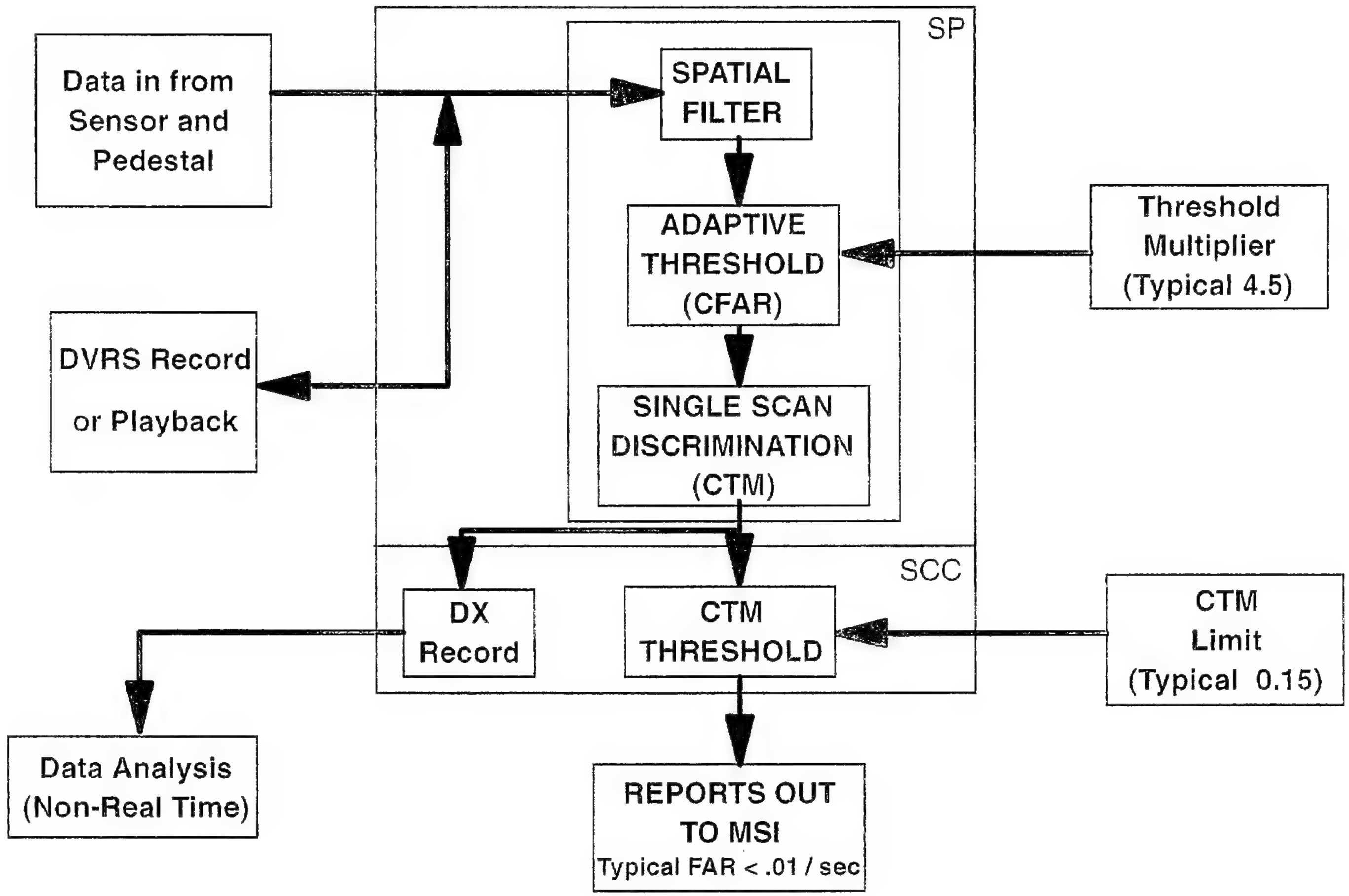
Data Flow Block Diagram
Horizon Infrared Surveillance Sensor



The following data results are based on an analysis of 25 tests events where the target was an inbound TLX towed target and the HISS was operated in a normal scan mode. Test events where there was evidence that the TLX plumer did not burn properly or the HME did not get up to the required temperature were eliminated from this data analysis.

Also, the TLX data does not include runs with extremely bad weather. Due to safety constraints, the aircraft towing the target was required to operate under visual flight rules (VFR) and could not be operated in extremely bad visibility conditions.

The detection data was processed using a detection merging algorithm to cluster groups of detections from a frame into a single detection. This detection merge algorithm is part of the current HISS Phase 3 processing.

This algorithm was useful because it reduces the amount of data to analyze and provides a correct *count* of detections. It does not affect the overall detection ranges associated with detection reports.

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Overview of Data Analysis

- 25 Data Runs
  - Inbound TLX towed target runs
  - HISS scan mode only
  - Good HME burns only
  - Weather conditions above VFR minimums

- Detection Merging Algorithm
  - Clusters groups of detections from a frame
  - Part of current HISS phase 3 processing
  - Provides a correct count of detections
  - Does not effect overall detections ranges

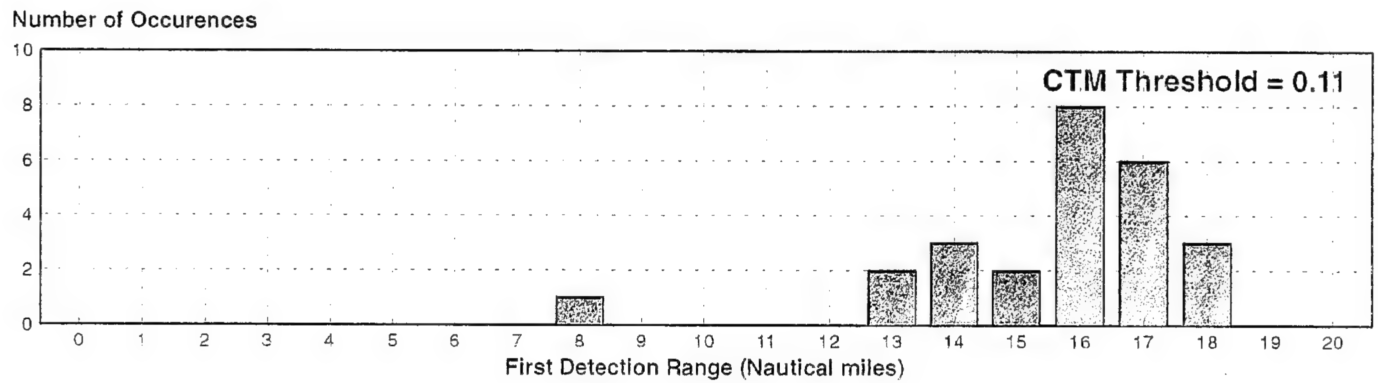
This figure shows the first detection range and the probability of detection for the 25 runs. For presentation purposes, the detection ranges were rounded to the nearest nautical mile.

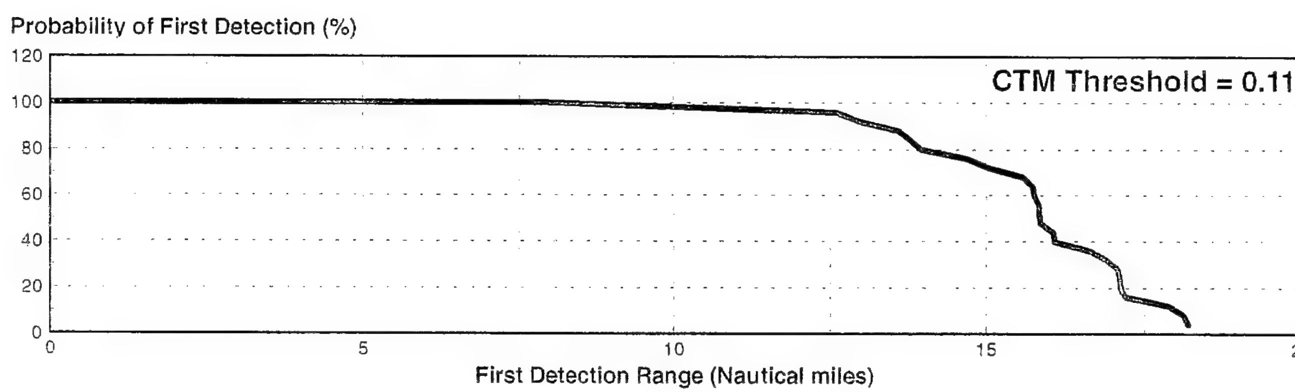
Note that only detections above a CTM of 0.11 are included. Early FAR analysis indicated that a CTM limit of 0.11 would produce a FAR of about 1/sec under typical clutter conditions. This is the threshold that is used throughout this data analysis.

However, this was not the CTM limit that was used during testing to threshold detection reports to the MSI interface. The CTM threshold to the MSI interface was typically 0.15 or higher. This will be discussed in more detail later.

From this data distribution, one can see that the maximum first detection range was about 18 nmi, the minimum first detection range was about 8 nmi, and the median first detection range was about 16 nmi.

Probability of Detection
TLX Towed Target - 25 sorties



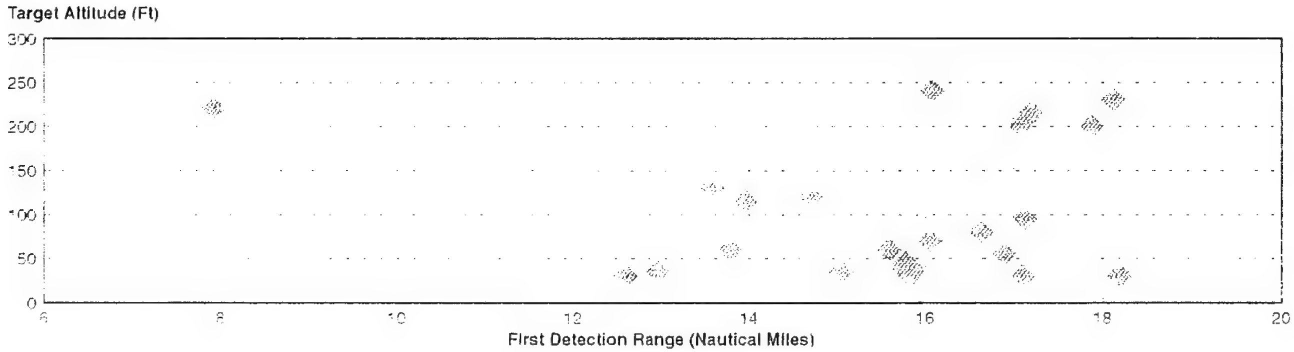


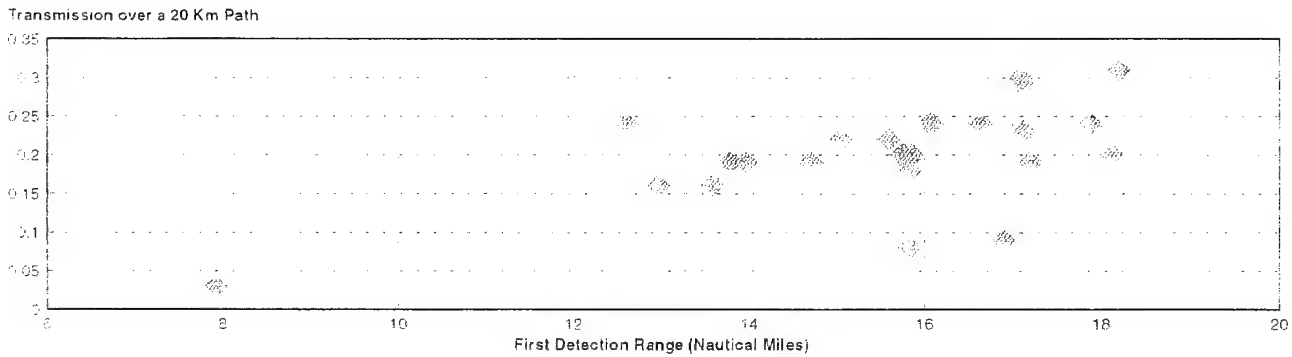
The test events using the TLX towed targets were typically conducted in a sequence of four inbound *burn* runs per day. The first run was usually around 200-ft altitude, and the next three runs were each at lower altitudes, approaching the intended altitude of 30 ft.

This figure shows the effects of target altitude as compared with the effects of atmospheric transmission in-band over a 20 Km path on first detection range. In the top chart, there is no apparent correlation between altitude and detection range. The longest detection range was at a high altitude. In the bottom of the figure, however, there does appear to be a correlation between atmospheric transmission on detection range. The longest detection range occurred during the time of the highest IR transmission. The shortest detection range occurred during the time of the lowest IR transmission.

On the previous figure, it was apparent that on a single day you could see the effect of altitude on reducing detection range. But if you look at all of the runs, it appears that the TLX altitude was not the most significant factor on reducing detection range, rather the overwhelming factor is the change in atmospheric transmission from day to day.

Target Detection Range
Altitude vs Transmission



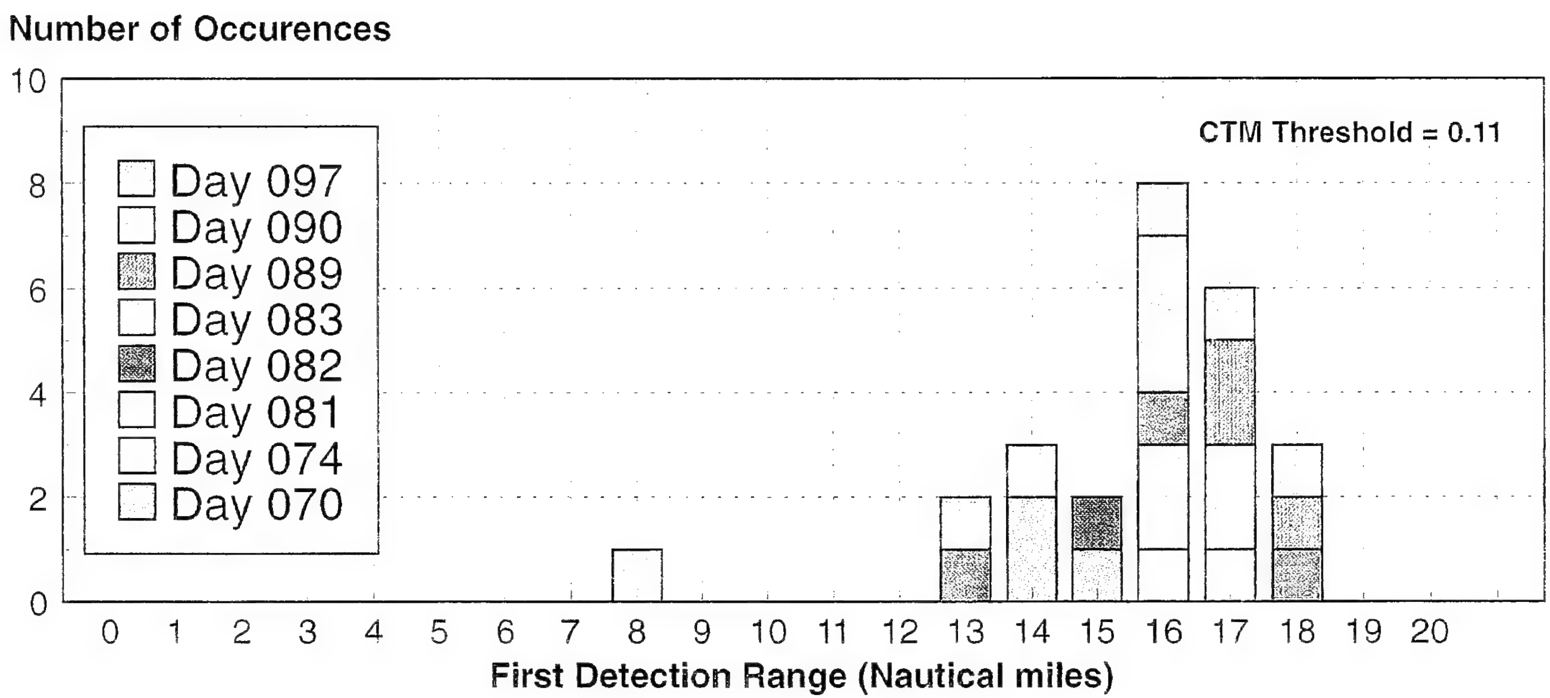


This figure shows a stacked bar graph that distributes the 25 maximum detection ranges by test day. From this distribution, some daily trends in the data can be seen. As expected, there are some days when the HISS performed better than others. For example, on day 089, the HISS had three long detection ranges; and, on day 083, the HISS had the shortest detection range.

On other days, the ranges were more evenly distributed for a single day. For example, on day 082, the dominate factor on detection range appears to be the change in altitude of each of the four runs. The first run was at 200-ft altitude and had the longest detection range, the fourth run was at 30-ft altitude and had the shortest detection range.

Also day 082 had an anomalous refraction condition due to a strong positive temperature gradient extending up to about 100-ft altitude. This resulted in the lower altitude runs appearing against a sea clutter background that contributed to the shorter detection ranges.

Target Detection Range
TLX Towed Target- by test day



During the MSI tests, the CTM limit was varied between 0.15 and 0.25 to maintain a low FAR (approximately 0.01/sec).

This figure compares the detection ranges between the CTM threshold used at the time of testing and a CTM threshold of 0.11, which results in a FAR of about 1/sec under typical clutter conditions.

This shows that the average probability of first detection range is about 1 nmi further when using the lower CTM threshold.

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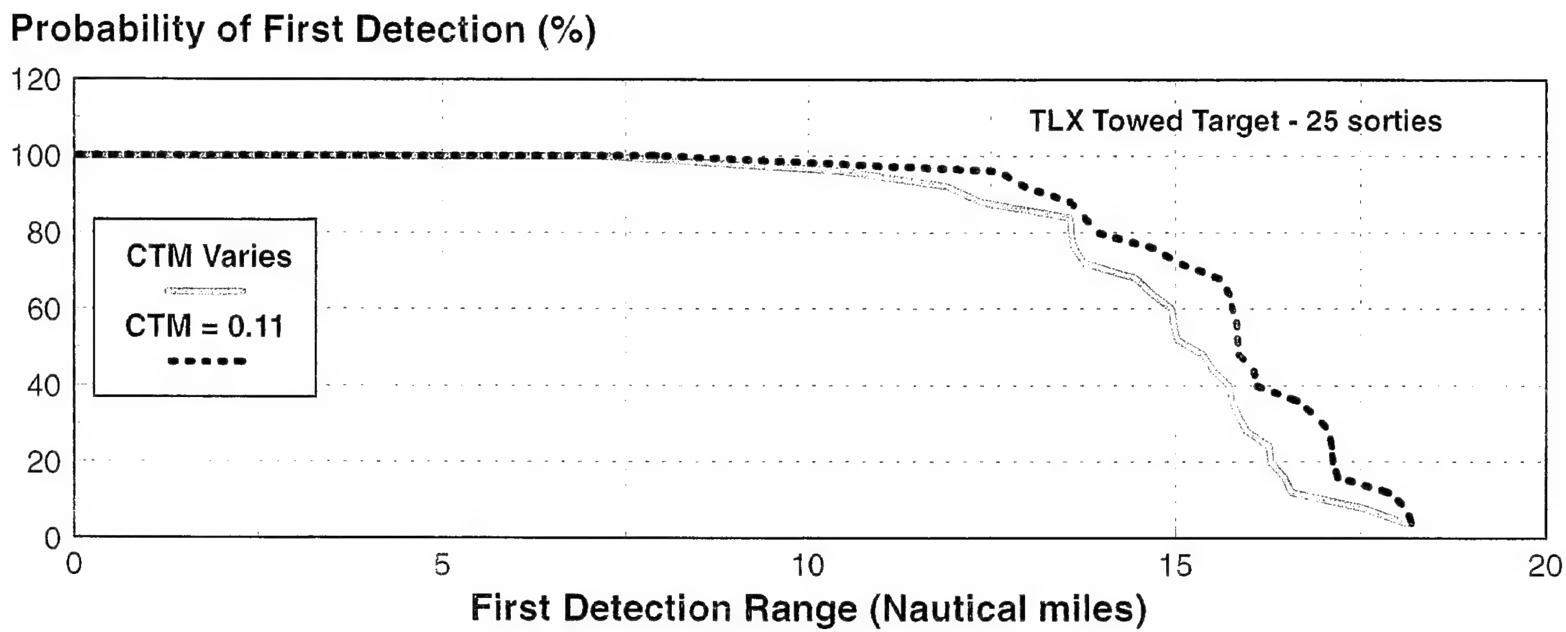
TLX Detection Ranges
At Actual Reporting Thresholds

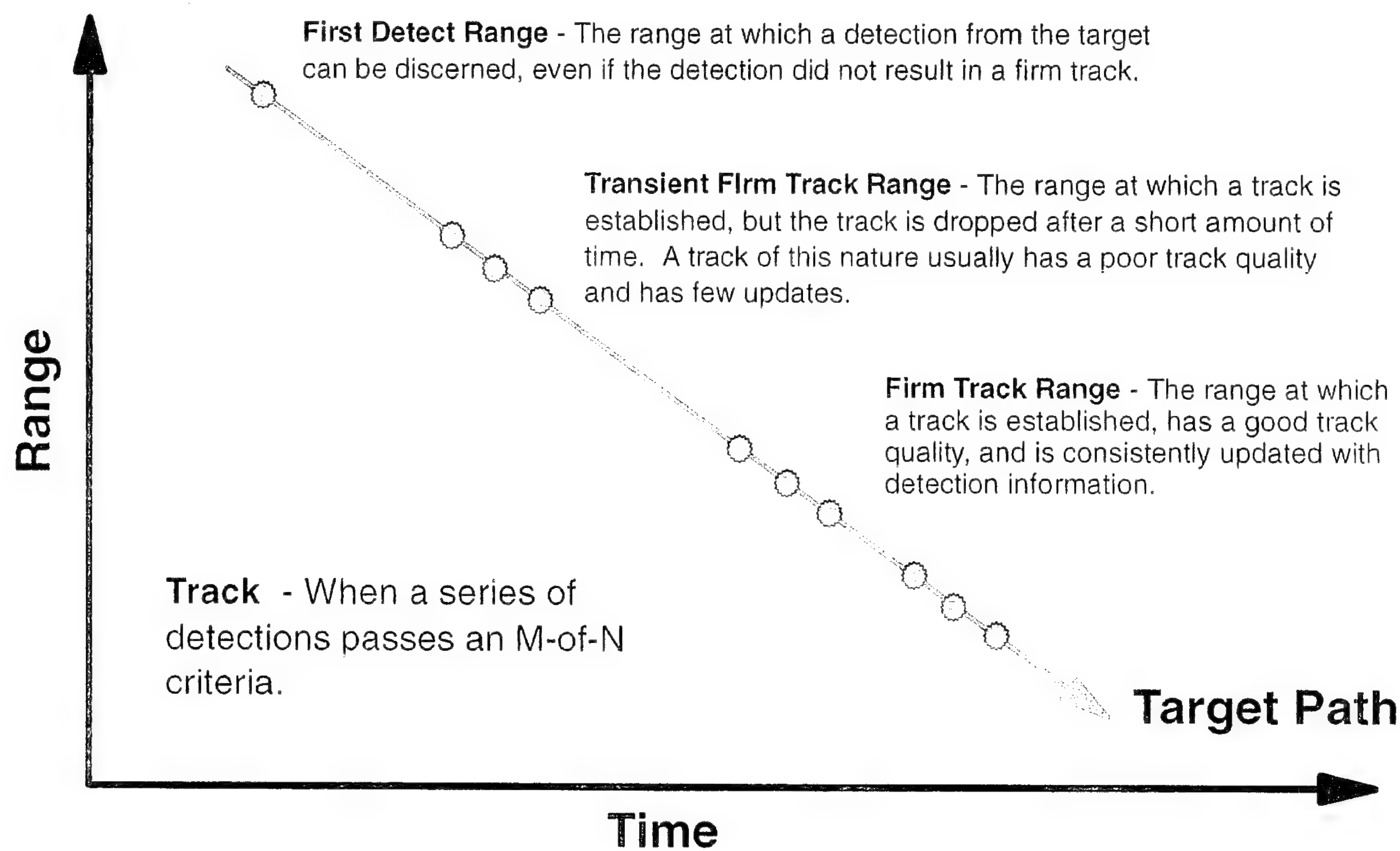


In support of the MSI data analysis effort, the first detection ranges were compared with the first track ranges for the 25 data runs. Since the HISS Phase 2 system does not have a track function, the following definitions were used to analyze the data: first detection, transient firm track, and firm track.

For a series of detections, the criteria for a track is when there were detections on two of three scans. The criteria for a *drop track* is when there are not detections for five scans in a row.

Therefore, if a series of detections develops a track but then drops track, it is considered to be a transient firm track, and if a series of detections does not drop track it is considered to be a firm track.

Definitions for MSI Data Analysis

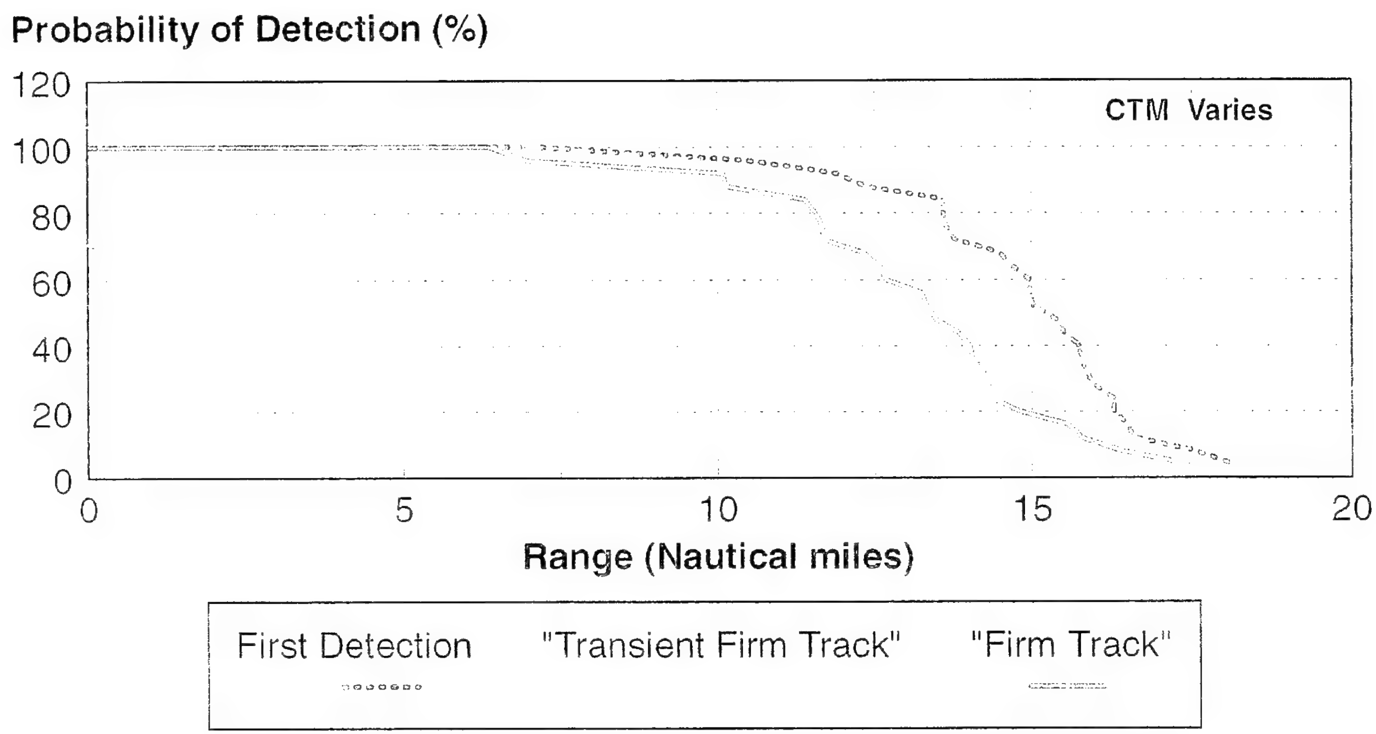


Using the definitions detailed previously, this figure compares the first detection, transient firm track, and firm track ranges.

For this comparison, use the various CTM thresholds used at the time of testing to report detections to the MSI interface.

This figure shows that at the 50-percent probability of detection point, the firm track range is about 2 nmi less than the first detection range and the transient firm track range is about 1 nmi less than the first detection range. At least some of this reduction in track range is due to the variation in the TLX amplitude that was discussed earlier.

Detection and "Track" Ranges
TLX Towed Target - 25 sorties



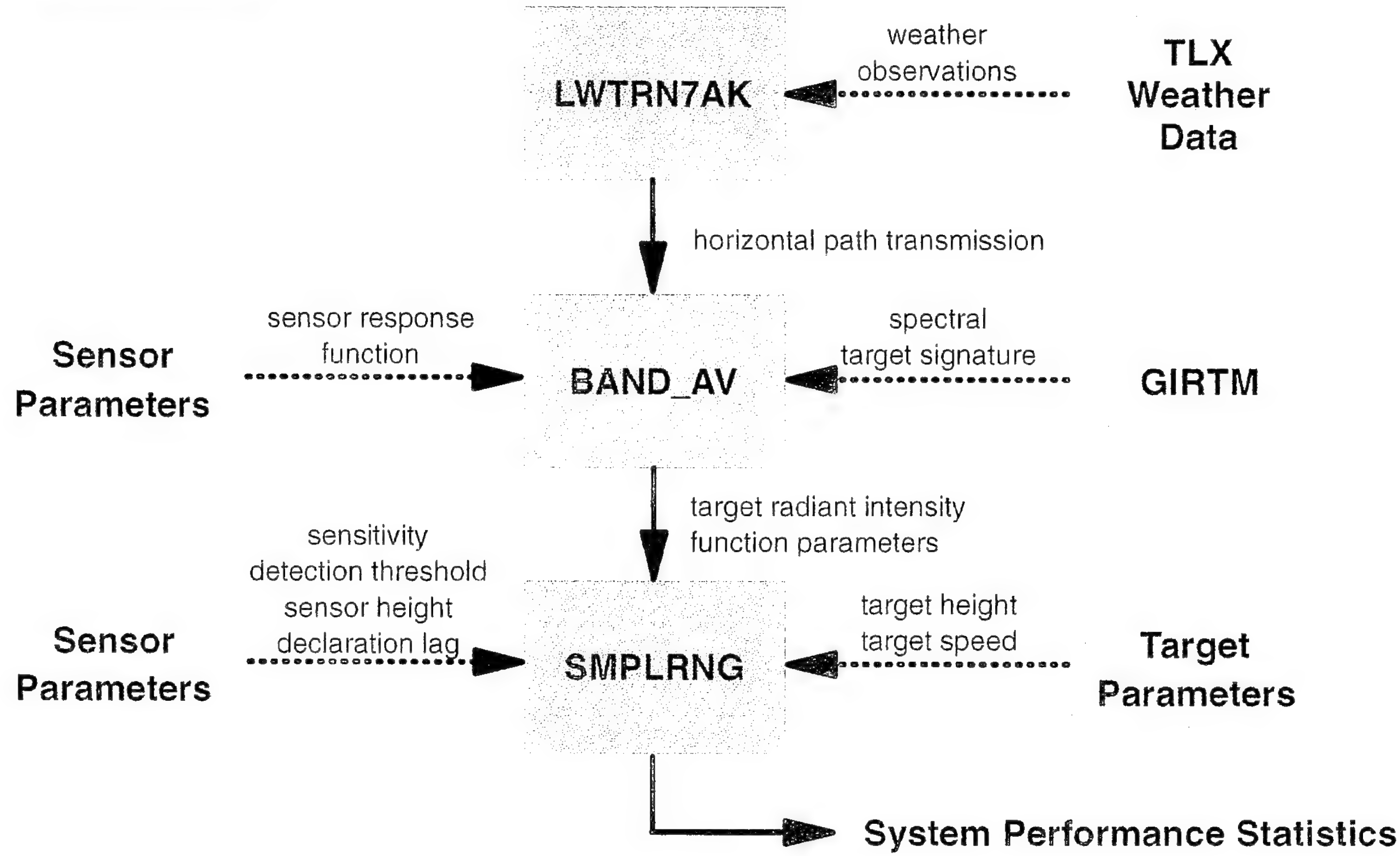
Finally, the measured detection range performance from the Wallops Island tests is compared against predicted detection range performance. This shows the methodology developed at NSWCDD to predict detection range performance based on sensor modelling weather observation data.

Program LWTRN7AK reads in a series a weather observations from a weather database, run LOWTRAN7 multiple times, and outputs path transmission files for each weather observation.

Program BAND_AV uses these output files to calculate the band averaged transmitted contrast irradiance based on a specified sensor response function and spectral target signature. For these calculations, the spectral target signature is obtained from general IR target model.

Program SMPLRNG calculates detection range based on BAND_AV output along with specified sensor parameters such as mounting height, sensitivity, detection threshold, etc. SMPLRNG also limits maximum detection range based on horizon obscuration under variable refraction conditions.

Statistical Performance Analysis

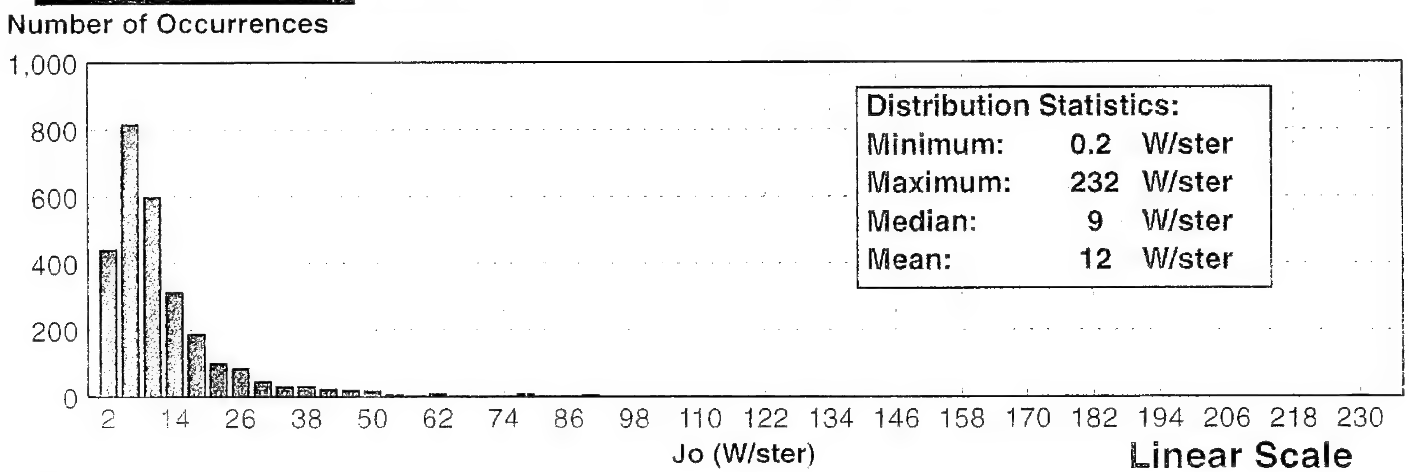


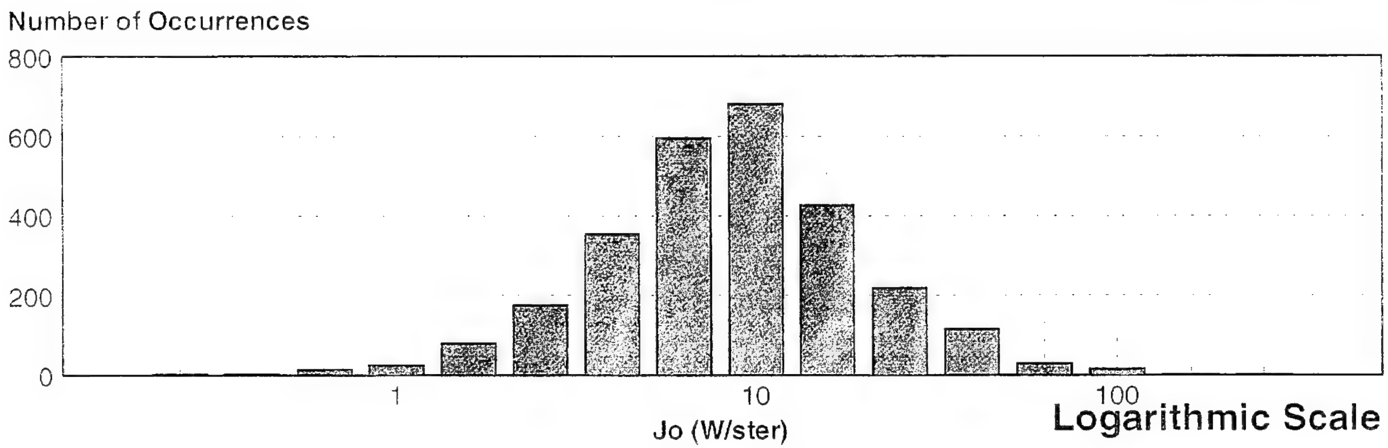
Using Wallops Island meteorological data as input, LOWTRAN was used to calculate transmission versus range factors for each of the 25 TLX runs. This data was then used to calculate the radient intensity at the target source, also known as the target zero-range radient intensity, J_0. A J_0 value was calculated for every detection in the 25 runs.

This resulted in a wide distribution of calculated target intensity values. This wide distribution is due to a number of error sources: inaccuracy in the LOWTRAN atmospheric calculations, variations in the sensor response for a given day (a fixed value of NEI = 2 E-14 was used throughout this analysis), variation in the apparent target intensity due to atmospheric refraction effects, and attenuation to the target intensity due to obscuration of the target discussed earlier.

The top figure shows a histogram of the calculated J_0 values on a linear scale. The bottom figure shows the same distribution presented on a logrithmic scale. (Note that the bin widths are not of equal size on this figure.) On this scale, the distribution has a uniform bell-shape centered on about 10 W/sr, which is consistent with the calculated values for median and mean.

Calculated Target Intensity
Wallops Island Met Data



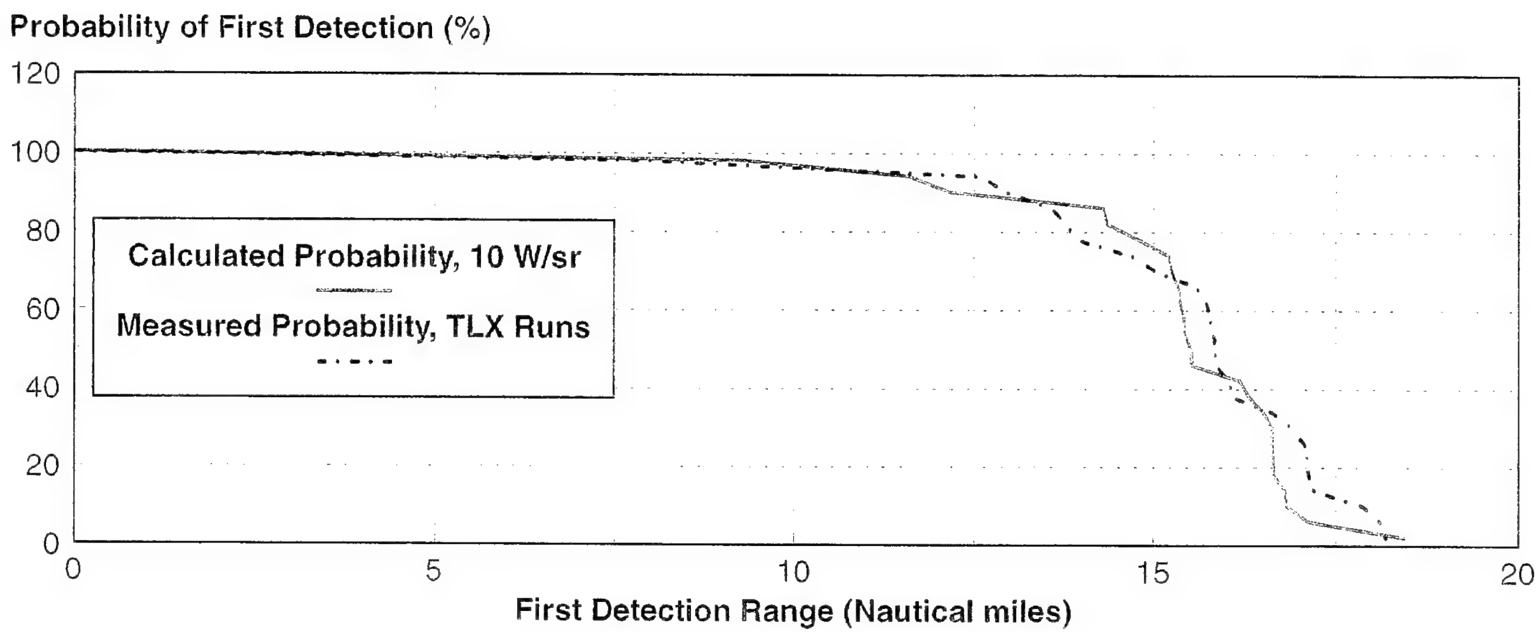


The statistical performance analysis model was used to predict the probability of first detection based upon sensor modelling, the weather conditions for each run, and a target intensity of 10 W/sr.

This figure shows that there is close agreement between the results of the 10-W/sr target prediction and the Wallops Island test results. Although the IR signature of the TLX target with the 10-in. HME was originally calculated to be at least 20 W/sr due to the significant obscuration of the target when facing at front-aspect angle it is presumed that the average target signature was something less than 20 W/sr.

Therefore, it is reasonable that the HISS detection range performance is consistent with the result of a 10 W/sr target under these weather conditions.

Comparison
10 W Target Prediction and Wallops Island Test Results



Although there were large fluctuations in the apparent intensity of the TLX, the HISS performed extremely well at detecting the target. The 50-percent probability of first detection range was about 16 nmi.

On a single day you could see the effect of the TLX altitude on reducing detection range. But when you look at all of the runs the most significant effect on detection range is from atmospheric transmission.

The probability of first detection was improved by about 1 nmi when using a detection threshold that resulted in a FAR of about 1/sec rather than a FAR of about 0.01/sec.

Using the definitions detailed earlier, at the 50-percent probability of detection point, the first firm track range is about 2 nmi less than the first detection range.

Based upon a comparison with a statistical model, the TLX target ranges obtained were consistent with an IR signature of about 10 W/sr.

Summary

- Although there were fluctuations in the apparent intensity of the TLX, the HISS performed extremely well at detecting the target.
- The most significant factor on reducing detection range was transmission rather than TLX altitude
- The probability of first detection improved by 1 nmi when using the lower detection threshold
- At the 50% probability of detection point, the first detection range is about 2 nmi farther than the first firm track range
- The performance we achieved was consistent with predicted results

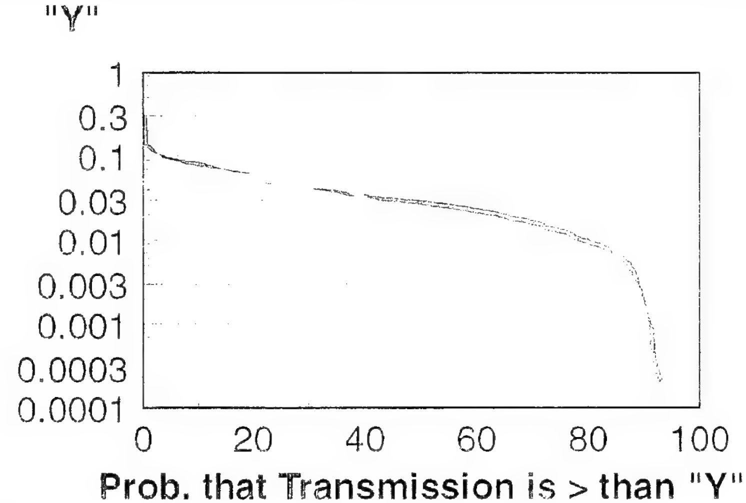
The performance of the system can be predicted for other operating areas through the use of statistical weather databases.

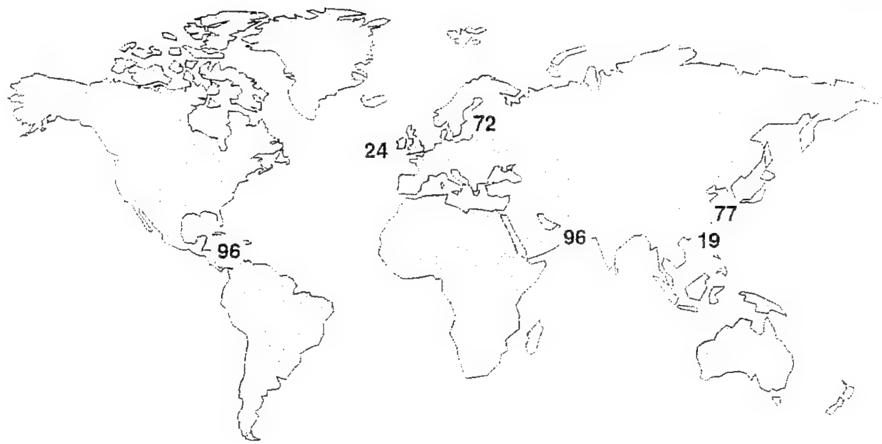
One commonly used weather database is the *Random 384* or *R384*. The sample was intended to represent the four following geographic areas with equal weight: Baltic Sea, Yellow Sea (Korea),. Gulf of Oman (Persian Gulf), and Caribbean Sea. Each area is represented by 8 randomly selected weather sample per month for a total of 8*12*4=384 samples.

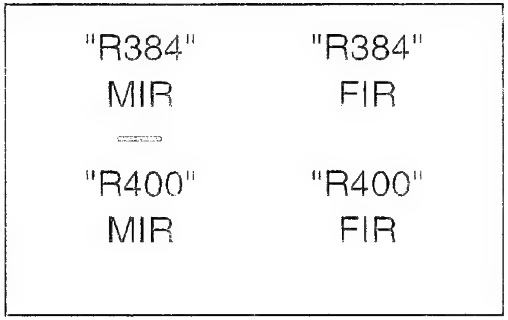
For the Gulf of Oman and Caribbean Sea, it was possible to sample eight observations per month from these actual locations. For the Baltic Sea and the Yellow Sea, however, the samples were made up from available weather samples from the nearby area. For the Baltic Sea, samples were comprised from observations from the Gulf of Finland and from open ocean measurements at the same latitude as the Baltic Sea. For the Yellow Sea, samples were comprised from observations from the region between the Yellow Sea and East China Sea and from measurements from the central portion of the East China Sea.

R384 Weather Sample

- 96 samples from each of the following general locations
  - Baltic Sea
  - Yellow Sea
  - Gulf of Oman
  - Caribbean Sea

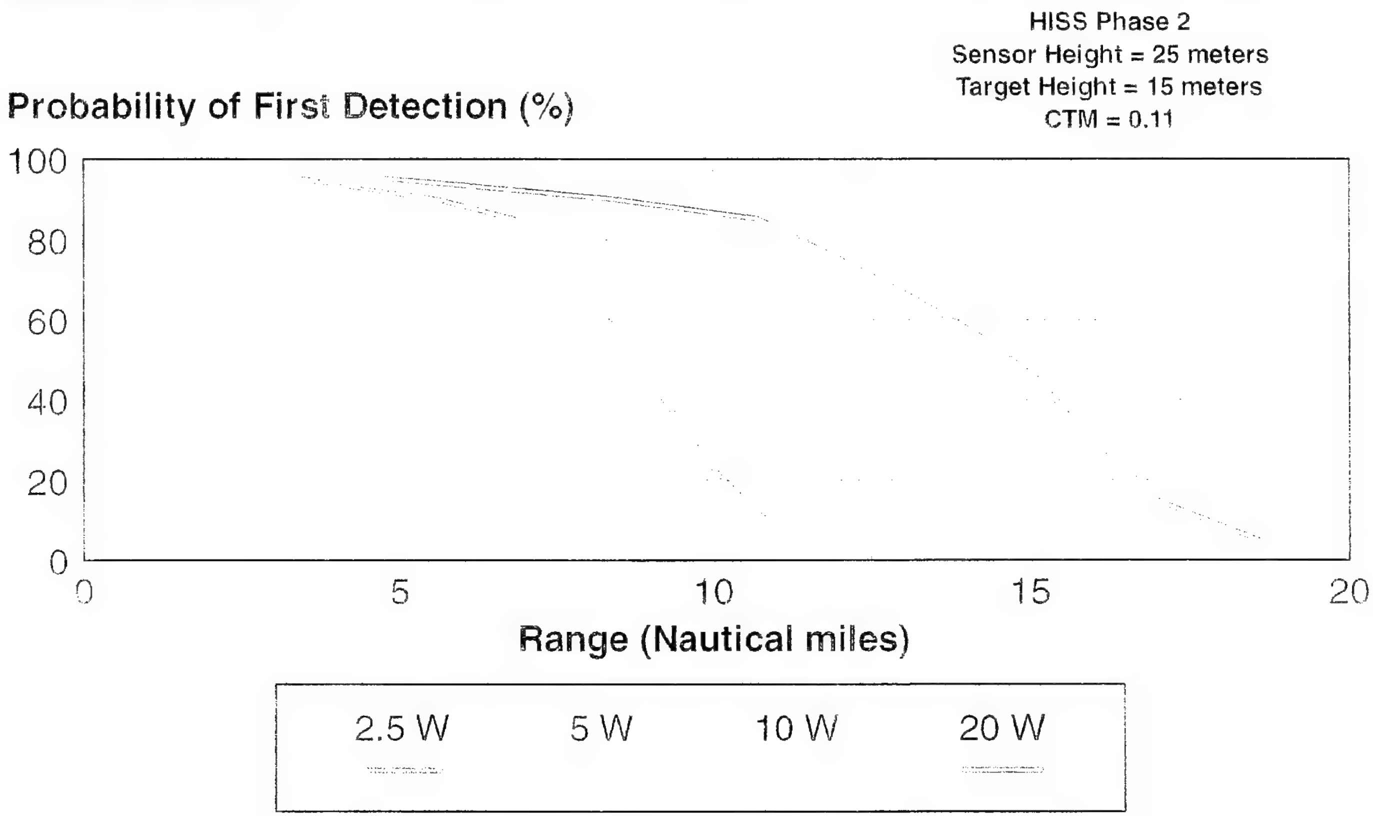






This figure shows the HISS Phase 2 system performance which can be expected against four notional targets whose signatures are 2.5, 5, 10 and 20 W/sr in the R384 weather environments. These targets are all assumed to be flying at an altitude of 15 meters and CTM reporting threshold is fixed at CTM - 0.11.

Predicted Performance
Using R384 Weather Sample



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Patrick A. Dezeeuw

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Commander
Naval Surface Warfare Center, Dahlgren Division (Code F44)
17320 Dahlgren Road
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